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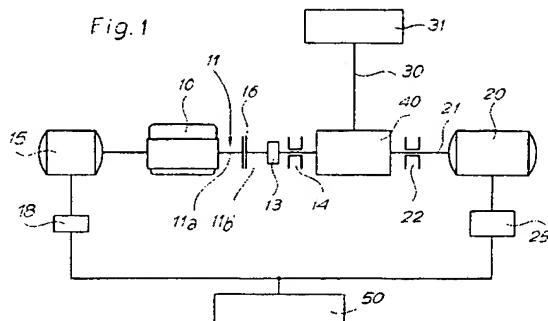
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(54) **Hybrid propulsion system for vehicles, in particular for urban use.**

(57) The propulsion system for vehicles comprises a heat engine (10), an electric motor (20), means (31) for effecting transmission to the wheels of the vehicle, means (15) for generating electrical energy associated with said heat engine (10) and means (50) for storing the electrical energy. The heat engine (10) and the electric motor (20) are connected to the transmission (31) via an epicyclic gearing (40), the heat engine and the electric motor (20) are connected, respectively, to a first and a second input shaft (11b, 21) of said epicyclic gearing, and the output shaft (30) of said epicyclic gearing is connected to the transmission (31) of the vehicle.



The present invention relates to a new hybrid propulsion system for vehicles, namely a system comprising at least a heat engine and an electric motor, in accordance with the preamble of Claim 1.

The hybrid systems proposed hitherto can be divided in two main categories:

a) series hybrid vehicles, in which all the power necessary for traction is supplied by the electric motor, powered both by batteries, in turn charged by a generator actuated by the heat engine, and directly by the generator itself. The heat engine in this case is dimensioned so as to supply the mean power used, while the electric motor must be able to supply the power and the torque required in all the situations in which the vehicle is used. A speed-changing unit is generally required, since the entire operating range cannot be covered by the starting torque and maximum power characteristics of current electric motors.

The situation as regards the emissions of the heat engine is favourable with reference to a test cycle since the heat engine operates within a fixed speed range, and therefore without transients, and moreover supplies a limited power. The situation is less advantageous at a constant speed; in fact, the emissions as well as the consumption levels are penalized by the efficiency of the electric drive, which is less than that of a mechanical drive.

b) parallel hybrid vehicles, in which both the electric motor and the heat engine may be coupled alternately or simultaneously to the transmission of the vehicle. The electric motor is in this case smaller than that used in a series hybrid vehicle, but the heat engine must frequently adapt its operation to the speed variations of the vehicle, thus partly losing the advantage of a reduction in emissions, which is precisely that of the series hybrid solution. Furthermore a speed-changing unit is essential. Control of the speed-changing unit as well as activation and deactivation of the engine and motor and adjustment of their load is very complex.

A complete overview of the state of the art relating to hybrid propulsion systems is contained in A.F. Burke's "Hybrid/Electric Vehicle Design Options and Evaluations", SAE 920447.

The aim of the present invention is to provide a hybrid propulsion system which overcomes the drawbacks of conventional hybrid systems both of the series and parallel type.

More particularly, the present invention aims to provide a system which allows the engine and motor to be used in series or in parallel depending on the application conditions, without the system requiring a speed-changing unit.

These and other aims and advantages, which will become clear to those skilled in the art from reading the description which follows, are obtained by means of the combination of characteristic features according to Claim 1.

Further characteristic features and advantageous embodiments of the system according to the invention are indicated in the appended sub-claims.

With the system according to the present invention, the heat engine produces, as in the series hybrid engines, a power output less than the maximum power output required (in practice not much greater than the mean power used) for propulsion of the vehicle, and this power is partly used mechanically for propulsion, while the electric motor supplements the difference between the power supplied by the heat engine and the power which the vehicle requires for propulsion. The excess power produced by the heat engine is absorbed by an electric generator which recharges the batteries and/or directly powers the electric motor.

The invention is illustrated in detail below with reference to the accompanying drawing, in which a possible non-limiting embodiment of the present invention is shown. In the drawing:

Fig. 1 shows the basic diagram of an embodiment of the invention;

Fig. 2 is an axial section through a possible embodiment of the epicyclic gearing which connects the engine and motor to the drive wheels of the vehicle; and

Fig. 3 is an axial section through a further embodiment of the epicyclic gearing.

With reference initially to the diagram of Fig. 1, the propulsion system comprises a controlled- or spontaneous-ignition heat engine 10 equipped with its own mechanical or electronic speed regulator (not shown). A generator 15, rotating at the same number of revolutions as the heat engine 10, is directly connected to the heat engine 10. However, it is also possible for the electric generator 15 to be driven via a suitable transmission gearing.

A regulator 18, which has the function of controlling the power supplied, voltage, etc., is associated with the generator 15. A transmission shaft 11 connects the heat engine to a first input shaft of an epicyclic gearing, generally denoted by 40 and described in more detail below, which connects the engine to the transmission generally denoted by 31 via an output shaft 30 of the epicyclic gearing 40 itself.

The shaft 11 is divided into two portions 11a and 11b connected together by a clutch 16 which, whenever required, enables the heat engine 10 to be disengaged from the transmission. Downstream of the clutch 16 there is a free wheel 13 which allows the portion 11b of the shaft 11 to rotate only in the direction of rotation of the heat engine, and a

brake 14, which prevents rotation of the portion 11b of the shaft 11 in either direction when the clutch 16 is disengaged. The free wheel 13 could also be dispensed with.

A second input shaft of the epicyclic gearing 40 has associated with it, via a shaft 21, an electric traction motor 20 of one of the known types (direct current, separate excitation, permanent magnet, synchronous with variable reluctance, etc.). The motor 20 is controlled by a main regulator 25 which, in addition to its own function as regulator of the motor, interacts with the regulator 18, with the speed regulator of the heat engine 10, with the pedal of the accelerator and with a speedometer which detects the speed of the vehicle.

The shaft 21 may have associated with it a brake 22 which allows said shaft to be locked when this is necessary in order to use only the heat engine in an emergency.

The system illustrated in Fig. 1 is completed by a set of batteries 50 which are charged by the generator 15 and which supply energy to the electric motor 20.

The epicyclic gearing 40 may be realized in various ways. It is important, however, that it should be an epicyclic gearing with two input shafts and an output shaft, with the output shaft being connected to the drive wheels, while the input shafts are respectively connected to the heat engine 10 and electric motor 20. Obviously, during free-running or downhill travel, the power input shaft is the transmission shaft and the two output shafts must be braked. Furthermore the internal ratio is chosen so that both the engine 10 and motor 20 contribute, with their characteristic torque, to the formation of the drive torque input to the transmission 31.

In other words, the gearing must allow the addition of power outputs of the same order of magnitude, but with different characteristics, since that of the heat engine is achieved at a high speed with a low torque, whereas that of the electric motor is also obtained at a low number of revolutions with a high torque.

Figs. 2 and 3 show two possible embodiments of the epicyclic gearing 40.

In the embodiment according to Fig. 2, a first gear wheel 41 of the gearing 40 is keyed onto the shaft 11b, which receives the movement from the heat engine 10. An internal crown gear 42 is keyed onto the shaft 21 actuated by the electric motor 20. A series of gear wheels 43 (two of which are visible in Fig. 2), mounted on a planet-wheel carrier or train carrier 44, mesh with the gear 41 and the crown gear 42. The train carrier 44 is integral with a gear wheel 30, which represents the output of the epicyclic gearing 40. Via a pair of gear wheels 33, 34, the movement is transmitted to the crown gear

35 integral with the housing of a differential 31, the output half-shafts 36, 37 of which transmit the movement to the drive wheels of the vehicle.

In this embodiment, therefore, the torques supplied by the engine 10 and motor 20 are introduced via the so-called sun gears of the gearing (i.e. the gear wheel 41 and crown gear 42), the sun gear with a smaller diameter being connected to the heat engine. This takes account of the fact that the heat engine operates at a greater angular velocity, supplying a low torque, while the electric motor, which is able to supply a high torque at a low number of revolutions, is connected to the gearing via the sun gear with a larger diameter.

In the embodiment according to Fig. 3, the portion 11b of the shaft 11 has keyed on it a gear wheel 45 which meshes with a series of gear wheels 46 mounted idly on a train carrier 47 integral with the shaft 21 of the electric motor 20. Each gear wheel 46, which rolls on the wheel 45, is integral with a respective gear wheel 48, which rolls on another gear wheel 49 coaxial with the gear wheel 45 and hence with the two shafts 11 and 21. The gear wheel 49 is integral with the gear wheel 30 which transmits the movement, via the wheels 33, 34, to the differential 31, in a similar manner to the embodiment according to Fig. 2.

In the embodiment according to Fig. 3, therefore, the torque supplied by the heat engine 10 is introduced into the gearing 40 in this case also via a sun gear of small diameter, while the torque of the electric motor 20 is introduced via the train carrier 47. The movement which is output is received by the second sun gear 49. However, the condition is satisfied, whereby the low torque of the heat engine (supplied at a high number of revolutions) is introduced via a wheel of small diameter rotating at high speed, while the high torque supplied at a low operating speed by the electric motor 20 is introduced via a component (train carrier) rotating at a low speed.

As known from mechanics, the speeds of rotation of the two input shafts and the output shaft are linked together by the relation, called the Willis formula, which in the embodiment according to Fig. 2, is:

$$(1)$$

$$K = \frac{N_{21} - N_{30}}{N_{11} - N_{30}}$$

where  
 $K$  is the internal transmission ratio of the gearing, which characterizes the

- $N_{11}$  gearing and depends on its geometry,  
 $N_{11}$  is the speed of rotation of the shaft 11,  
 $N_{21}$  is the speed of rotation of the shaft 21,  
 $N_{30}$  is the speed of rotation of the shaft 30.

Furthermore, the torques on the three shafts are linked together by the following relations:  
(2)

$$C_{11} = \frac{K}{1 - K} C_{30} \quad 15$$

(3)

$$C_{21} = \frac{1}{K - 1} C_{30} \quad 20$$

where:

- $C_{11}$  is the torque transmitted by the shaft 11,  
 $C_{21}$  is the torque transmitted by the shaft 21,  
 $C_{30}$  is the torque transmitted by the shaft 30.

In the embodiment according to Fig. 3, the Willis formula can be written as follows:  
(4)

$$y = \frac{N_{30} - N_{21}}{N_{11} - N_{21}} \quad 30$$

$y$  being the internal transmission ratio of the gearing in this case.

It can be shown that the two embodiments of the gearing are equivalent and therefore the relations (2) and (3) between the torques are always valid, if:  
(5)

$$y = \frac{K}{K - 1} \quad 45$$

From the equations (1), (2) and (3) it emerges that the speed of rotation of the shaft 30, and hence (ultimately) the speed of the vehicle, may be varied by varying the speed of either of the drive shafts 21 and 11. Since the heat engine 10 operates within a fixed range (or within a limited number of predetermined speed ranges), variation in the speed of the vehicle is obtained, for each speed range of the heat engine 10, by varying the speed of rotation of the electric motor 21. Moreover, since the resistance torque on the drive wheels of the vehicle, and hence on the output shaft 30 of the gearing 40, is fixed, the distribution of the torques supplied by the engine 10 and motor 20 is determined by the ratio of the gearing. For this reason it is necessary to choose a ratio  $K$  which enables the low torque of the heat engine and the high torque of the electric motor to be exploited.

Since the torque supplied by the heat engine 10 is constant (within a fixed operating range), modulation of the torque  $C_{11}$  supplied to the epicyclic gearing 40 of the heat engine 10 is obtained by varying the power consumption of the generator 15.

The electric motor 20, finally, must in turn supply a variable power output, depending on the torque  $C_{11}$  (which is a function of the resistance torque  $C_{30}$ ) and the number of revolutions  $N_{21}$  (which is a function of the vehicle's speed of travel).

This having been stated, the following comments may be made regarding the operation of the hybrid propulsion system described above:

#### Operation in solely electric mode:

In this mode of operation the clutch 16 is disengaged and the brake 14 prevents rotation of the shaft 11b. The electric motor 20 ensures traction during forward travel and backward travel by reversing its own direction of rotation, as well as energy recovery during free-running or downhill travel. Reverse travel is possible only in electric mode, or in series hybrid mode if the heat engine 10 is in operation.

#### Operation in hybrid mode:

In hybrid mode the beginning of the cycle, upon start-up of the vehicle, is similar to electric mode, with the clutch 16 disengaged and the brake 14 applied. Upon operation of the accelerator the vehicle starts with the electric motor alone, and the heat engine (if not already running) is started up and runs at a speed close to idle speed, charging the batteries. This mode of operation corresponds

to conventional series hybrid operation.

When the vehicle reaches a given speed, of the order of 15-25 km/h, the regulator 25 engages the clutch 16 and releases the brake 14. The shaft 11b thus starts to rotate and if, during the manoeuvre, the speed of the vehicle is assumed to be constant initially, the revolutions of the electric motor are proportionally reduced as the clutch 16 engages, since a part of the movement is now supplied to the gearing 40 by the heat engine 10. The system is now operating in parallel hybrid mode.

With further pressure on the accelerator pedal, the vehicle accelerates owing to the increase in the speed of the electric motor 20, the speed of the heat engine 10 having to remain constant.

Upon reaching a higher speed, the heat engine 10 is accelerated and passes from the preceding operating range to a new operating range with a higher speed of rotation. This may result both in a decrease in the speed of rotation of the electric motor 20 and an increase in the speed of the vehicle. This transition of the heat engine 10 to a higher speed range with a corresponding reduction in the speed of rotation of the electric motor may be repeated several times until higher vehicle speeds are reached in each case, the need for regulation of the heat engine with two or more speed stages depending, inter alia, on the characteristics of the vehicle and the performance required in terms of a reduction in the polluting emissions.

Let us assume now that the vehicle has to negotiate a slope of gradually increasing steepness: the regulation system will increase excitation of the electric motor 20 and reduce that of the generator 15 so as to transfer a larger percentage of the torque of the heat engine 10 to the epicyclic gearing 40.

If, with the generator 15 completely deenergized, the steepness of the slope should increase further (and therefore, in other words, the torque  $C_{30}$  increase), the control system intervenes, reducing the number of revolutions of the electric motor 20, so as to slow down the vehicle and thus reduce the torque required. If the vehicle slows down beyond a certain speed value, the reverse sequence of operations with respect to that described for acceleration is performed, and the heat engine passes to a lower speed range where it supplies a larger torque. If this is not sufficient because the steepness is still increasing, the speed is further reduced until, at a certain steepness, operation in parallel hybrid mode is no longer possible. As a result the clutch 16 is disengaged, the brake 14 applied and the vehicle advances in series hybrid mode, with all the power supplied by the electric motor 20 and the power of the heat

engine 10 being transferred to the generator 15 which supplies the electric motor 20 and/or charges the batteries 50.

All the operations described above are controlled, as mentioned, by the regulator 25 on the basis of the signals received from the components of the propulsion system (speed of rotation of the engine and motor and torque produced, speed of travel of the vehicle) as well as the commands received from the driver (acceleration and reversal of travel).

The main advantages of the hybrid propulsion system described above are as follows:

- greater efficiency, lower consumption and reduced emission levels compared to series hybrid propulsion systems, since part of the thermal power is transmitted directly to the wheels mechanically via the epicyclic gearing, without passing via the electrical components and batteries;
- lower emission levels compared to parallel hybrid systems since the heat engine runs at one or a very small number of fixed-speed ranges (two or three), with scarcely any transients;
- electric motor which is smaller, lighter and more economical compared to the series hybrid since it has to supply only a part of the power required, the other part being directly supplied mechanically by the heat engine;
- elimination of the speed-changing unit, required in conventional series and parallel hybrid systems.

### Claims

1. Propulsion system for vehicles, comprising a heat engine (10), an electric motor (20), means (31) for effecting transmission to the wheels of the vehicle, means (15) for generating electrical energy associated with said heat engine (10), and means (50) for storing the electrical energy, characterized in that the heat engine (10) and the electric motor (20) are connected to the transmission (31) via an epicyclic gearing (40), said heat engine and said electric motor (20) being connected respectively to a first and a second input shaft (11b, 21) of said epicyclic gearing, the output shaft (30) of said epicyclic gearing being connected to the transmission (31) of the vehicle.
2. Propulsion system according to Claim 1, characterized in that the ratio of the epicyclic gearing is chosen so as to allow the combination of the low torque supplied at a high number of revolutions by the heat engine with the high torque supplied at a low number of revolutions

by the electric motor.

3. Propulsion system according to Claim 1 or 2, characterized in that the input shaft (11b) connected to the heat engine (10) is integral with a main wheel (41) of the epicyclic gearing (40), the input shaft (21) connected to the electric motor (20) is integral with another main wheel (42) of the epicyclic gearing, and the output shaft (30) is linked to the train carrier or planet-wheel carrier (44) of the said epicyclic gearing.

4. Propulsion system according to Claims 1 and 2, characterized in that the input shaft (11b) connected to the heat engine (10) is integral with a main wheel (45) of the epicyclic gearing (40), the input shaft (21) connected to the electric motor (20) is integral with the train carrier or planet-wheel carrier (47) of the epicyclic gearing (40), and the output shaft (30) is connected to another main wheel (49) of the epicyclic gearing (40).

5. Propulsion system according to one or more of the preceding claims, characterized in that a friction clutch (16) is arranged on the shaft (11) which connects the heat engine (10) to said epicyclic gearing (40) and in that a braking means (14) is arranged between said friction clutch and the epicyclic gearing (40).

6. Propulsion system according to one or more of the preceding claims, characterized in that a braking means (22) is provided on the shaft (21) which connects the electric motor (20) to the epicyclic gearing (40), said braking means allowing operation with the heat engine alone.

7. Propulsion system according to one or more of the preceding claims, characterized in that the electric motor (20) has associated with it an electronic regulator (25) which, depending on the commands received, the travel condition of the vehicle and the speed of rotation of the heat engine (10) and the generator (15), controls the electric motor (20), causing it to operate in either direction of rotation, at the desired torque and number of revolutions, or causing it to operate as a current generator.

8. Propulsion system according to one or more of the preceding claims, characterized in that the electric generator (15) is controlled by an electronic regulator (18) performing the function of a rectifier, voltage regulator and electric power output controller.

9. Propulsion system according to Claim 7, characterized in that the heat engine (10) is provided with a speed regulating device governed by the regulator (25) of the electric motor (20).

10. Propulsion system according to one or more of the preceding claims, characterized in that the heat engine (10) is controlled so as to function at a predetermined number of rotational speeds.

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Fig. 1

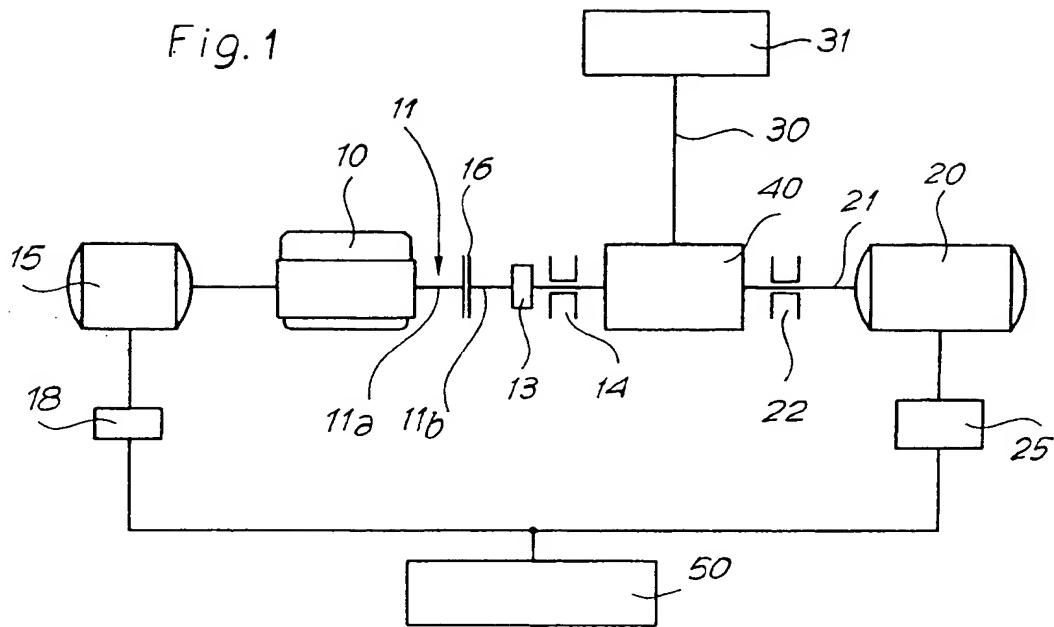


Fig. 2

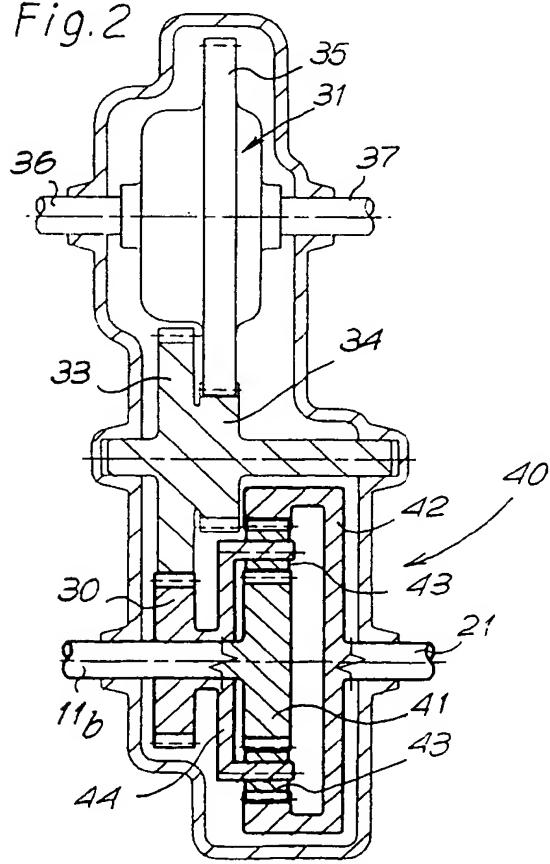
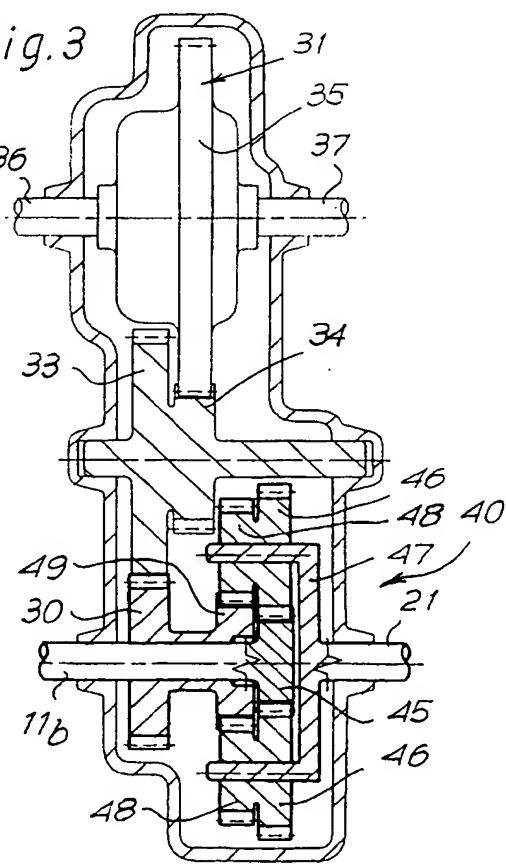


Fig. 3





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## EUROPEAN SEARCH REPORT

Application Number  
EP 93 83 0414

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.6)						
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim							
X A	DE-A-25 10 623 (KÖRNER, HELMUT) * page 3, line 1 - line 37 * * page 4, line 27 - page 3, line 33 * * page 5, line 10 - line 11 * * page 5, line 23 - line 30 * * claims 1,2,5,6; figure * ---	1-3,5,6 7	B60K6/04						
X	DE-A-25 02 400 (KÖRNER, HELMUT) * the whole document * ---	1-3							
X A	FR-A-2 679 839 (JEUMONT SCHNEIDER INDUSTRIE) * page 1, line 1 - line 9 * * page 7, line 1 - page 8, line 24 * * figure 2 * -----	1,3 5,7							
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)						
			B60K						
<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>THE HAGUE</td> <td>28 March 1994</td> <td>Topp-Born, S</td> </tr> </table>				Place of search	Date of completion of the search	Examiner	THE HAGUE	28 March 1994	Topp-Born, S
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